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Management of fusarium basal rot (*Fusarium oxysporum* f. sp. *cepae*) on shallot through fungicidal bulb treatment

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ABSTRACT

Fusarium basal rot caused by *Fusarium oxysporum* f.sp. *cepae* is an economic disease of shallot. Field experiments were conducted at Debre Zeit during 2006 and 2007 cropping seasons to determine effective fungicides and their method of application for the management of fusarium basal rot of shallot. The field was naturally infested with F. oxysporum f. sp. cepae and treatments were arranged in randomized complete block design in four replications. Five fungicides, Mirage 50 WP, Folicur 25 EC, Seed plus 30 WS, Penncozeb 80 WP and Ridomil Gold 68 WG were evaluated as seed bulb dressing and bulb dip treatments against basal rot in the field and storage. Bulb dressing with Mirage, and dip treatment in Seed plus reduced the disease incidence by 40% and 43%, respectively over control. These fungicides also resulted in a significant reduction in severity, basal rot affected cull bulbs on shallot. Bulb rot during three months of storage on concrete ground floor and on wire mesh shelves was also reduced by seed bulb treatment over control. The highest increase in yield was obtained from bulb dressing with Mirage (42%) and Seed plus (45%) and from bulb dip treatment in Seed plus (44%) over control. Fusarium basal rot caused 45% loss in yield and 12–30% of bulb loss in the storage. The study showed that basal rot of shallot can be managed effectively by seed bulb dressing or dip treatment in Mirage or Seed plus.

1. Introduction

Shallot (*Allium cepa* var. *ascalonium* Barker) is an important *Allium* crop in many countries. It is preferred over the common onion for its shorter growth cycle and its distinct flavor that persists after cooking (Rabinowitch and Currah, 2002). It is widely cultivated in Ethiopia, and the total area under shallot and onion is around 17,588 ha, with an average yield of about 7.5 t/ha (Aklilu, 1997; CSA, 2010).

Fusarium basal rot (FBR) caused by *Fusarium oxysporum* f. sp. *cepae* (Snyder and Hans) is one of the major problems of shallot in Ethiopia. It attacks roots and bulbs of shallot and onion, producing symptoms ranging from rotting of roots, slight discoloration to total necrosis of the basal plate. It can be recognized in the field by yellowing and browning of leaves, which begin at the tip and move downward. Plants exhibit weak growth and may wilt. Eventually the fungus invades the entire bulb and causes rotting of internal scales (Rengwalska and Simon, 1986). Healthy looking bulbs may have a latent infection and they develop rot in storage later (Brayford, 1996). Incidence and severity of bulb rotting is high during the storage. In the USA, losses in the field due to FBR have been reported to range from 3 to 35% (Abawi and Lorbeer, 1972; Lacy and Roberts, 1982). Losses in storage can be even greater than losses in the field. In Brazil, rotting of infected bulbs in storage has been reported to range from 12 to 75% (Brayford, 1996; Stadnik and Dhingra, 1996). FBR can survive in the soil for long period of time through chlamydospores (Delahaut and Stevenson, 2004). Incidence of FBR on shallot in Ethiopia has been reported to range from 1 to 20% in black clay soils. However, its incidence is very high at the research centers of Ethiopia and even destroys most of the shallot germplasm collections (Getachew and Asfaw, 2000).

Resistance in some onion cultivars against FBR has been reported from some countries (Goldman, 1996; Cramer, 2000; Lopez and Cramer, 2004). However, no resistant variety of shallot or onion is available for farmers in Ethiopia. Effective control of the disease has been reported by soil fumigation with methyl bromide or treatment of transplants with benomyl (Jaworski et al., 1978; Koycu and Ozer, 1997). Tebuconazole has also been reported to control FBR (Ozer and Koycu, 1998). Seed treatment with benomyl, carbendazim, carboxin, maneb and methoxymehtyl mercury chloride (Koycu and Ozer, 1997; Cramer, 2000), prochloraz, tebuconazole and thiram (Ozer and Koycu, 1998) has been reported to reduce incidence of FBR in onion. In Ethiopia, Getachew and Asfaw (2000) reported that

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treating shallot bulbs with Beret special (fenpiclonil) reduced the damage due to FBR by 64%. Partial control of this disease using antagonistic microorganisms has also been reported (Rajendran and Ranganathan, 1996; Coskuntuna and Ozer, 2008). *Trichoderma harzianum* strain KUEN 1585 (commercialproduct, Sim®Derma, Symbiyotex.com, Istanbul) has been promoted for the control of fusarium basal rot of onion (Coşkuntuna and Özer, 2008).

In view of the scanty information on chemical control of FBR in Ethiopia, especially on shallot, studies were undertaken with the objective to identify effective fungicides and their method of application for the management of fusarium basal rot of shallot.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at Debre Zeit Agricultural Research Center (DZARC) during the 2006 and 2007 August to November with supplementary furrow irrigation. DZARC is located at 8° 44' N latitude and 38° 58' E longitudes at an altitude of 1980 m above sea level and is characterized by 851 mm mean annual rainfall and about 16.6 °C mean annual temperature. The experiments were conducted in alfisols and fields were previously cropped to shallot for several years and are naturally infested with *F. oxysporum* f. sp. *cepae (Foc)*. To know the distribution of pathogen in the field before planting from the experimental field was took soil samples randomly in the field.

2.2. Treatments and field experiment layout

The effect of five fungicides on FBR of shallot was studied in field experiments. Fungicides were evaluated by two methods of application, i.e., seed bulb wet dip treatment in aqueous suspension and seed bulb dressing. Shallot seed bulbs harvested from disease free area and uniform medium sized (15 g weight) were selected manually and treated with fungicides. Seed bulb dressing was done with Mirage 50 WP @ 6 g kg^{-1} [(prochloraz), Makhteshim Chemical works Ltd Agan, Beer-Sheva, Israel], Folicur 25 EC @ 4 ml kg^{-1} [(tebuconazole), Bayer AG, Leverkusen, North Rhine-westphalia, Germany], Seed plus 30 WS @ 10 g kg^{-1} [(carbendazim + metalaxyl + imidacloprid), fluenceagrichem, Victoria, Queensland, Australia], Penncozeb 80 WP @ 3.75 g kg^{-1} [(mancozeb), Cerexagri Inc., King of Prussia, Pennsylvania, USA] and Ridomil Gold 68 WG @ 4.41 g kg^{-1}[(metalaxyl-M 4% + mancozeb 64%), Syngenta AG, Basel, Switzerland]. Shallot bulb dressing was done with wettable powder/emulsifiable concentrate of the fungicides by making thick slurry of the required fungicide quantity in 5 ml water and applied on 0.5 kg of bulbs in polythene bags by shaking thoroughly and repeatedly for 5 min for uniform coating. Seed bulb wet dip treatment was done in aqueous suspension of Mirage 50 WP 10 g l^{-1}, Folicur 25 EC @ 5 ml l^{-1}, Seed plus @ 16.67 g l^{-1}, Penncozeb @ 6.25 g l^{-1} and Ridomil Gold 68 WG @ 7.36 g l^{-1} of water. Bulbs dipped in fungicide aqueous suspensions for 1 h under shade at room temperature (22 °C). Untreated shallot bulbs were dipped in water without fungicide was used as control. The experiment was arranged in a randomized complete block design (RCBD) with a total number of 11 treatments and 4 replications. The plot size was 4 m^2 with six rows and spacing between blocks and plots was 1 and 0.5 m, respectively. Inter row and intra row spacing was 0.4 m and 0.2 m, respectively. Cultivar Fedis, which is widely cultivated and susceptible to FBR was used in field trials in both seasons. After fungicide treatment for 2 h, bulbs were planted by hand on 1 August 2006 and 3 August 2007. Insecticide (Karate 25 EC 0.5 lt ha^{-1}) and fungicides (Penncozeb 80 WP and Ridomil Gold 68 WG; 2.5 kg ha^{-1} each) were used to control onion thrips (*Thrips tabaci*) and downy mildew (caused by *Peronospora destructor*) disease, respectively.

2.3. Disease assessment

During the 2006 and 2007 growing seasons, incidence of FBR in each plot was recorded beginning from September 18 and 17 on the basis of foliar symptoms six and five times, respectively at 13 day interval from the first appearance of the disease. Ten randomly-selected and pre-tagged plants from four central rows of each plot, excluding the outer two rows were used for severity assessment. At harvest time per plant severity of FBR was recorded on a 1-5 scale, where 1 = without any decay symptom, 2 = up to 10% rotted roots, 3 = 10–30% rotted roots with up to 10% rotted basal plates, 4 = completely rotted roots and 10–30% rotted basal plates and 5 = completely rotted roots and more than 30% rotted basal plates (Rengwalska and Simon, 1986). FBR severity scores were converted into percentage severity index (PSI) as

$$\text{PSI} = \text{Sum of numerical ratings} \times 100/\text{No. of plants scored} \times \text{Maximum score on scale}$$

2.4. Effect on yield and yield loss

Initial plant stand at 14 days after planting (DAP) and at harvest was recorded from each plot. Shallot bulbs were harvested from the four middle rows of each plot, to avoid the border effect. Harvesting was done 110 and 112 DAP in the first and the second seasons, respectively. After harvesting, culled out bulbs due to FBR were also recorded from each plot. The yield loss due to FBR was determined using the following formula:

$$\text{Relative yield loss (\%)} = (\text{Yp} - \text{Yup}) \times 100/\text{Yp},$$

Where Yp = yield of protected plot and Yup = yield of unprotected plot. The relative yield loss with different fungicides was calculated with reference to the best-protected plot.

2.5. Assessment of bulb rot in storage due to FBR

After harvesting, bulbs were cured for ten days and then 40 uniform sized apparently-healthy looking shallot bulbs per plot were stored for three months by two methods. One set of bulbs was kept on wire mesh shelves and the other on the ground (concrete floor) in single layers so that bulbs did not overlap each other. Treatments were arranged in a randomized complete block design (RCBD) with four replications. The number of decayed bulbs exhibiting symptoms of FBR was assessed six times during the entire storage period at 15 day intervals in both years. Rotted bulbs were removed after each assessment to avoid the spread of the pathogen to healthy bulbs. The number of healthy and diseased bulbs showing rotting of basal plate was recorded from each replicate at the end of storage, and finally incidence of FBR was calculated as percentage of total bulbs stored.

2.6. Statistical analyses

All data were subjected to analysis of variance (ANOVA) to evaluate the treatment effects using SAS ANOVA (SAS institute Inc, 2002). Duncan Multiple Range Test separated treatment means.

3. Results

3.1. Effect of fungicides on plant emergence

In 2006, the highest initial plant stand (86.5%) was recorded from bulb dip treatment in Seed plus, while the lowest was recorded in Folicur bulb dip treatment plots (60.1%). Bulb dressing in Seed plus and Mirage resulted in a higher initial plant stand count than other bulb dressing treatments as well as control 61.7% (Table 1).

During the 2007 cropping season, higher initial stand count (80.7–86.6%) among treatments was obtained from Seed plus followed by Mirage and Ridomil. However, Folicur applied as a bulb dip treatment resulted in lower initial stand as compared to control. Bulb dressing with different fungicides showed higher plant stand counts as compared to wet bulb dip treatment in both years. Wet bulb treatment in Folicur resulted in darkening fleshy scale of bulbs.

3.2. Effect of fungicides on field FBR incidence and severity

The typical FBR symptoms first appeared in the plots on the 46th and 45th DAP in 2006 and 2007, respectively. Incidence of disease increased with time differentially in treated and control plots. In both seasons, final FBR incidence recorded on 106 DAP was significantly different ($P \leq 0.05$) among treatments (Table 1). In 2006, final disease incidence was the highest in the control plots (26.5%), while the lowest disease incidence was recorded from dip treatment in Seed plus (14%). The bulb dip treatment in Folicur and Mirage resulted in 15 and 19.5% final disease incidence, respectively and they were equal to the Seed plus dip treatment. However, no significant difference in disease incidence was found between dipping in Penncozeb or Ridomil Gold and the non-treated control. Seed bulb dressing in Mirage and Folicur also proved effective in reducing the disease incidence to 14.7 and 15%, respectively and they were significantly better than Penncozeb and Ridomil bulb dressings as well as the control during 2006. Folicur during 2006 crop season performed equally well as the dip or dressing treatment, while Mirage was better as a bulb dressing and Seed plus as dip a treatment.

During the 2007 season, seed bulb dipping and dressing treatments significantly reduced final disease incidence in comparison to the control. The lowest final disease incidence was recorded from the dipping treatment with Mirage (11%), followed by Seed plus (12.5%) and Folicur (12.7%) in comparison to the control (20%). Out of the different fungicides evaluated for seed bulb dressing, Folicur proved the best and reduced final disease incidence to 11% and was followed by Ridomil Gold, Mirage, Seed plus and Penncozeb, which resulted in 12, 13.2, 14 and 16% disease incidence, respectively. Mean incidence of two years was the lowest with seed bulb dressing with Folicur followed by dip treatment in Seed plus, Folicur and bulb dressing treatment with Mirage.

The seed bulb treatment also effectively reduced disease severity during 2006 (Table 1). Folicur, Seed plus and Mirage as seed bulb dip treatment proved best and reduced the mean severity to 12.1, 16.7 and 17.9% in comparison to 23% in the untreated control. Similar trend was observed in 2007. Seed bulb dressing with Mirage, Seed plus and Folicur resulted in 12.9, 15.4 and 16.7% severity recorded at the harvest of 2006 season crop. The three fungicides proved effective in reducing the severity over control in 2007 as well. Generally the fungicides did not differ significantly in method of application in reducing incidence or severity of disease, but performance of Seed plus treatment was slightly better as a dip treatment as compared to bulb dressing, while Mirage was better as a bulb dressing than dip treatment on the basis of the mean of two years.

3.3. Cull-out bulbs at harvest

During the 2006 season, the cull-out bulbs at harvest due to FBR was significantly different ($P < 0.05$) among treatments (Table 2). Folicur as bulb dip and Seed plus as bulb dressing treatments resulted in significantly lower (1.5%) cull-out bulbs than the non-treated control (3.3%). The cull bulbs due to FBR disease in the second cropping seasons was significantly different ($P < 0.05$) among treatments. Folicur as a bulb dip treatment, Mirage and Seed plus as bulb dressing treatments resulted in relatively lower cull-out of bulbs as compared to other fungicide treatments. The overall mean of two seasons showed significantly lower cull-out of bulbs with Folicur as bulb dip treatment, Mirage and Seed plus as bulb dressing treatments over the non-treated control (Table 2).

3.4. Fusarium basal rot effect on shallot yield

In the 2006 cropping season, significant differences ($P < 0.05$) were observed among treatments in shallot bulb yield (Table 2). Among the various dipping treatments, the highest bulb yield of 9.0 t/ha was obtained from plots with the Mirage bulb dip treatment, followed by the dipping treatment in Seed plus (8.7 t ha^{-1}) and the lowest yield was recorded from the Penncozeb bulb dip treatment (5.7 t ha^{-1}) in comparison to the non-treated control plots (5.6 t ha^{-1}). Bulb dressing with Seed plus and Mirage resulted in 9.2 and

Table 1
Effect of fungicides on plant stand, fusarium basal rot incidence and severity of shallot.

Treatment	Plant stand (%)[a]		Mean plant stand (%)[b]	Plant stand at harvest (%)[c]		Mean final stand (%)[b]	Final incidence (%)[d]		Mean incidence (%)[b]	Severity (%)[e]		Mean Severity (%)[b]
	2006	2007		2006	2007		2006	2007		2006	2007	
Seed bulb wet treatment												
Mirage	71.2 abc	86.3 ab	78.8 a	62.8 a-d	71.7 ab	67.3 a	19.5 ab	11.0 d	15.2 c	17.9 a-d	14.1 bcd	16.0 b-f
Folicur	60.1 c	59.9 d	60.0 b	53.0 d	48.2 d	50.6 c	15.0 b	12.7 cd	13.8 c	12.1 e	13.8 bcd	12.9 f
Penncozeb	76.1 abc	79.0 ab	77.6 a	65.6 a-d	65.2 ab	65.4 ab	26.2 a	16.7 abc	21.5 ab	22.2 ab	16.2 abc	19.2 ab
Seed plus	86.5 a	86.6 ab	86.5 a	75.4 a	72.0 ab	73.7 a	14.0 b	12.5 cd	13.2 c	16.7 b-e	14.4 bcd	15.5 c-f
Ridomil Gold	80.6 ab	80.7 ab	80.7 a	66.9 a-d	66.7 ab	66.8 a	24.7 a	18.5 ab	21.6 ab	20.5 abc	16.8 ab	18.7 abc
Seed bulb dressing												
Mirage	72.6 abc	88.9 a	80.8 a	64.0 a-d	72.2 ab	68.1 a	14.7 b	13.2 bcd	14.0 c	12.9 de	13.1 cd	13.0 f
Folicur	69.5 abc	61.9 cd	65.7 b	55.8 bcd	50.0 cd	52.9 c	15.0 b	11.0 d	13.0 c	16.7 b-e	11.4 d	14.0 ef
Penncozeb	77.5 abc	79.4 ab	78.5 a	68.4 a-d	62.5 b	65.4 ab	25.0 a	16.0 a-d	20.5 ab	19.5 abc	16.7 abc	18.1 a-d
Seed plus	86.0 a	90.6 a	88.3 a	72.6 ab	75.5 a	74.0 a	19.5 ab	14.0 bcd	16.7 bc	15.4 cde	14.4 bcd	14.9 def
Ridomil Gold	82.4 a	89.4 a	85.9 a	70.5 abc	75.5 a	72.9 a	23.0 a	12.0 cd	17.5 bc	19.4 abc	14.8 a-d	17.1 b-e
Untreated control	61.7 bc	74.2 bc	67.9 b	54.4 cd	61.0 bc	57.7 bc	26.5 a	20.0 a	23.2 a	23.0 a	18.0 a	20.5 a

Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test.
[a] Percent of total planted bulbs at 14 days after planting (DAP).
[b] Mean values of two years.
[c] Percent of total initial count at harvest.
[d] Incidence assessment at 106 DAP.
[e] Severity assessed at 110 and 112 DAP in 2006 and 2007, respectively.

Table 2
Effect of fungicide treatments on fusarium basal rot disease cull-out bulb and shallot yields during 2006 and 2007 cropping seasons.

Treatment	FBR cull-out bulb (%)		Mean cull-out bulb (%)	Yield (t/ha)		Mean Yield (t/ha)	Relative yield Loss (%)
	2006	2007		2006	2007		
Seed bulb wet treatment							
Mirage	3.1 ab	0.8 ab	1.9 abc	9.0 a	9.0 ab	9.0 ab	9.5
Folicur	1.5 b	0.5 b	1.0 c	6.6 abc	5.4 b	6.0 c	39.6
Penncozeb	2.8 ab	0.7 ab	1.7 abc	5.7 c	6.1 ab	5.9 c	40.5
Seed plus	1.8 ab	0.7 ab	1.2 abc	8.7 ab	10.9 a	9.8 a	1.8
Ridomil Gold	2.8 ab	1.2 ab	2.0 ab	8.0 abc	7.3 ab	7.6 abc	23.3
Seed bulb dressing							
Mirage	1.6 ab	0.5 b	1.1 bc	9.1 a	9.9 ab	9.5 ab	4.9
Folicur	1.6 ab	1.0 ab	1.3 abc	6.8 abc	6.5 ab	6. 7 bc	33.0
Penncozeb	3.0 ab	0.8 ab	1.9 abc	6.1 bc	7.2 ab	6.7 bc	33.1
Seed plus	1.5 b	0.6 b	1.1 bc	9.2 a	10.7 a	9.9 a	0.0
Ridomil Gold	2.8 ab	1.0 a	1.9 abc	7.7 abc	8.9 ab	8.3 abc	16.3
Untreated control	3.3 a	1.0 ab	2.1 a	5.6 c	5.3 b	5.5 c	45.1

Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test.

9.1 t ha^{-1} yield, respectively, while the lowest among the bulb dressings was from the Penncozeb (6.1 t ha^{-1}) treatment. Mirage applied as bulb dip or as dressing treatment resulted in high reduction in disease control and an increase in yield. Seed plus was slightly better as a bulb dressing treatment in increasing the yield. Among different fungicides, Penncozeb was the least effective when applied as a bulb dressing in terms of yield.

In 2007, the highest yield (10.9 t ha^{-1}) among the different bulb dip treatments was obtained from Seed plus treated plots, followed by Mirage (9.0 t ha^{-1}) in comparison to 5.3 t ha^{-1} in the non-treated control (Table 2). Folicur as a bulb dip treatment resulted in the smallest yield increase among the different dip treatments. Bulb dressing with Seed plus and Mirage resulted in 10.7 and 9.9 t ha^{-1} shallot yield, respectively. In general, from the results of the two seasons, the Seed plus and Mirage treatments produced higher yields than the non-treated control, while Folicur and Penncozeb were not effective.

3.5. Yield losses due to FBR disease

The mean values of disease incidence and severity of the two seasons in the non-treated control plots were 23.2 and 20.5%, respectively (Table 1), while the plot protected with Seed plus as bulb dressing had 16.7% incidence and 14.9% severity. The overall mean final plant stand at harvest in the control and Seed plus as bulb dressing was 57.7 and 74%, respectively. It resulted in corresponding differences in shallot yield also. There were highly significant yield differences in both seasons between unprotected plots and plots protected with fungicides ($P < 0.01$) (Table 2). Seed plus as a bulb dressing resulted in a mean yield of 9.9 t ha^{-1} during the two years. In comparison, the lowest bulb yield was obtained from the unprotected control plots (5.5 t ha^{-1}), revealing a yield loss of 45.1% due to FBR. Application of different fungicides reduced the loss due to the disease to different levels. The bulb dip treatments with Seed plus and bulb dressing with Mirage had the lowest yield loss of 1.8 and 4.9%, respectively, while the highest yield loss was in the unprotected control followed by bulb dip treatment in Folicur and Penncozeb at 45.1, 40.5 and 39.6%, respectively over the maximum protected plots.

3.6. Fusarium basal bulb rot in storage

Harvested bulbs from all treatments stored by two methods showed differences in incidence of FBR among the treatments ($P = 0.05$). During the 2007 storage, the highest FBR rotted bulbs (30.5%) were recorded in the control stored on the ground (Table 3). Bulbs harvested from all seed bulb wet dip treatments had lower incidence of FBR during storage on the ground, but statistically were not different in rotting with the non-treated control. Bulb dressing in Folicur and Seed plus treatments showed the lowest bulb rots in ground storage, while the highest rot was recorded from the Ridomil and control plots.

During the 2008 ground storage conditions, bulb rot incidence showed differences among treatments ($P = 0.05$). Folicur as a bulb dip treatment resulted in significantly lower bulb rot (8.2%) than the other bulb dipping treatments and the non-treated control, while the highest bulb rot (20.5%) was in the dipping treatment with Ridomil, higher than the 19% in the non-treated control. Bulb dressing with Penncozeb, Mirage and Ridomil provided the lowest bulb rot, while the highest rot was recorded in the non-treated control. Folicur as a dip, Penncozeb, Mirage and Ridomil as a bulb dressing resulted in the lower bulb rot during the three months of storage.

The mean data of the ground storage from the two years showed that seed bulb dressing in Seed plus, Folicur and Mirage and bulb dip in Mirage effectively extended the disease control in storage.

The FBR rotted bulbs in the 2007 mesh shelf storage were different among the treatments ($P = 0.05$). In the wire mesh shelf storage, fungicides as bulb dip treatments reduced FBR, but statistically were not different from the non-treated control. Bulb dressing with Penncozeb resulted in the highest bulb rot (23.2%), followed by the control (23.0%) as compared with other treatments. The lowest bulb rot was recorded with Folicur and Mirage as a bulb dressing, which was significantly less than the control.

In 2008, bulb rot incidence in mesh storage bulbs was not significantly different among the treatments. However, Ridomil, Mirage and Penncozeb as a bulb dip and the control had the highest bulb rot incidence among the treatments (Table 3). Among the bulb dip treatments, Seed plus had the lowest bulb rot incidence (9.7%). The incidence of bulb rot in 2007 storage was higher than 2008 in both storage type conditions. In general, the two year mean value of the mesh storage results showed that the highest bulb rot incidence was recorded from the non-treated control. Folicur as bulb dressing had the lowest bulb rot incidence among the treatments. In general, bulb rot was found to be higher in the ground storage than in the wire mesh storage.

Table 3
Effects of fungicides on fusarium basal rot incidence under different bulb storage condition during 2007 and 2008.

Treatment	Ground storage bulb rot incidence (%)		Mean of two years (%)	Mesh shelf storage bulb rot incidence (%)		Mean of two years (%)
	2007	2008		2007	2008	
Seed bulb wet treatment						
Mirage	17.7 ab	12.7 bc	15.2 c	17.2 ab	13.5 a	15.4 ab
Folicur	24.5 ab	8.2 c	16.4 bc	13.5 ab	11.0 a	12.2 ab
Penncozeb	25.5 ab	16.0 ab	20.7 abc	19.0 ab	12.7 a	15.9 ab
Seed plus	20.0 ab	12.0 bc	16.0 bc	12.7 ab	9.7 a	11.2 ab
Ridomil Gold	24.7 ab	20.5 a	22.6 ab	14.5 ab	13.7 a	14.1 ab
Seed bulb dressing						
Mirage	21.0 ab	7.7 c	14.4 c	11.5 b	10.7 a	11.1 ab
Folicur	16.2 b	11.2 bc	13.7 c	10.0 b	11.7 a	10.9 b
Penncozeb	24.0 ab	7.5 c	15.7 bc	23.2 a	11.7 a	17.5 ab
Seed plus	14.7 b	12.2 bc	13. 5 c	13.7 ab	10.7 a	12.2 ab
Ridomil Gold	30.2 a	8.2 c	19.2 abc	14.2 ab	9.7 a	12.0 ab
Untreated control	30.5 a	19.0 a	24.7 a	23.0 a	12.7 a	17.9 a

Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test.

4. Discussion

All fungicides except Folicur showed higher plant establishment than the non-treated control. Seed plus as a dip or dressing and Ridomil as a bulb dressing showed significantly higher establishment than the control in 2006. Also in 2007, Seed plus, Ridomil and Mirage as bulb dressing increased plant establishment over the non-treated control. Naik and Burden (1981) reported a 28% increase in plant establishment when onion seed sets were dusted with fungicide Granosan 200 (benomyl 15% + mancozeb 60%) before planting. However, initial plant of stand treated bulbs with fungicides was not satisfactory, which may suggest that there were other contributory factors to this problem besides FBR. During shallot early plant growth period (August 2-12) there was a heavy rainfall condition, which was highly affected the shallot initial plant stand population due to continuous high soil moisture condition. Plant stand establishment of bulbs treated by dipping or dressing with Folicur was lower as compared to other fungicides, though it was similar to the control. Onion seed treatment with Folicur was effective against FBR under field conditions (Ozer and Koycu, 1998), but in the present study, it showed some toxic effect. It might be due to exposure softer tissue of seed bulbs of shallot as compared to onion seeds.

Both incidence and severity of FBR were reduced by seed bulb treatment, protecting seedlings from seed bulb and soil borne infections. The trials showed that fungicidal treatment of seed bulbs before planting, especially in Seed plus or Mirage as a bulb dip or dressing treatments were effective not only in reducing the disease incidence and severity significantly, but also resulted in a corresponding increase in yield and a reduction in bulb rot incidence in storage. Ozer and Koycu (1998) indicated that onion seed treatment with prochloraz was the most effective for controlling *F. oxysporum* induced damping-off in infested soil.

The development of FBR disease on shallot was most successfully reduced with Seed plus, which is a formulated mixture of two fungicides (10% carbendazim + 10% metalaxyl-M) and one insecticide (10% imidacloprid). Carbendazim has been reported to be very effective on onion, with a single seed treatment, for *Foc* under field conditions (Barnoczkine-stoilova, 1988; Abd-El-Razik et al., 1990). Naik and Burden (1981) reported that dusting of onion sets with Granosan 200 (benomyl 15% + mancozeb 60%) before planting reduced basal rot of harvested bulbs by 77% in the first year; and pre-planting dips in benomyl (100 μ/ml) for 15 min reduced basal rot by 65%. Benomyl on application is converted into carbendazim, which might have controlled the disease. Mechanical wounding has been reported to increase FBR, and the high increase in seed corn maggot (*Delia platuria)* on FBR affected plants has been reported (Everts et al., 1985). According to Delahaunt and Stevenson (2004), the fungus invades through wounds or root scars at the base of the bulb and root maggot feeding injury may serve as the major entry sites for it. The possibility of implication of other soil insects in FBR cannot be ruled out and imidacloprid component of Seed plus might be playing some role in reducing wounding by soil insects. The initial root system of all *Allium* species is small and delicate, and because of it these crops require high nitrogen input in cultivation. Penncozeb, a contact fungicide, failed to reduce the disease and increase the yield in comparison to systemic fungicides like Mirage, Folicur and Seed plus mixture. Ridomil gold, which contains metalaxyl and Penncozeb, was generally not effective. Metalaxyl is a highly effective chemical to control oomycetes. Penncozeb alone or as a component of Ridomil gold might have given some protection in initial stages only unlike systemic fungicides, which enter into the plant system and provide protection for a much longer period. In general, seed bulb dressings reduced the disease incidence and severity more as compared with dip treatments. However, Seed plus dipping performed better than its seed dressing. There was no significant difference in initial and final plant stand between dipping and dressing treatments.

Bulb yields for all Seed plus and Mirage treatments were higher than those of other treatments. The seed bulb treatment with Folicur reduced the FBR incidence and severity, but the initial stand of shallot was lesser in comparison to Seed plus and other fungicides. Therefore, in spite of equal disease control from Seed plus and Mirage, yields were lower in Folicur bulb dip and dressing treatments. Influence of fungicides on soil pathogens depends on many factors. There are suppressive and conducive soils that affect the incidence of diseases caused by fusarium wilt fungi (Mace et al., 1981). Some of the major factors include physical, chemical and biochemical properties of the soil, and the nature and concentration of the fungicides applied as well as the time of year (Vyas, 1988). Moderate to high soil temperature, poor drainage, low soil fertility, less than 4 years onion rotation and occurrence of pink root and maggots favored FBR (Schwartz, 2004) and high soil temperature occurring early in the season also results in seedling damping-off. Often, high temperatures occur later in the season, while *Foc* is pathogenic over the temperature range of 22–38 °C (Kehr et al., 1962; Abawi and Lorbeer, 1972).

Debre Zeit Agricultural Research Center alfisols soils with histories of FBR consistently revealed high populations of *Foc* (an average of 8000 propagules/g oven-dry soil). However, it did not always follow that soil with high populations of the fungus had a history of high incidence of FBR even when susceptible cultivar of shallot was grown. This indicates that factors in addition to the inoculum density of the fungus influence the disease potential of naturally infested field soils. It appears that factors in the soil (biotic, abiotic or both) are involved, which reduce infection in many cases, but in certain soils either their absence or non-function allows a greater incidence of infection (Abawi and Lorbeer, 1971).

The most effective treatment in reducing the incidence of shallot FBR was Seed plus as a bulb dipping and resulted in highest mean yield (9.9 t ha^{-1}). The present study indicates that bulb treatment fungicides can be used as a tool or as a component of integrated FBR management. Fungicide treatments showed that the potential shallot yield is 9.9 t ha^{-1} compared with 5.5 t ha^{-1} obtained from the non-treated control. The mean yield data of the two years also indicated that Penncozeb as a bulb dipping treatment gave the lowest averaged yield (5.9 t ha^{-1}) among the fungicides. Naik and Burden (1981) indicated that the mixture of benomyl and mancozeb significantly reduced the incidence of basal rot in harvested bulbs and losses in the ambient storage condition. But in this study, Penncozeb showed the lowest performance in reducing FBR disease among all fungicide treatments. Unprotected plots with the highest disease incidence and severity yielded the least and suffered yield loss of 45.1% when compared to the best-protected plots. The present study has clearly demonstrated that FBR causes significant losses in shallot production in Ethiopia.

In 2006, fungicide treatments given to the seed bulbs showed differences in bulb rot incidence in the ground storage. Folicur and Seed plus applied as a seed dressing had the least bulb rot in 2006, while all fungicide treatments except Ridomil and Penncozeb reduced bulb rotting during ground storage in 2007. Rajapakse and Edirimanna (2002) reported that one pre-harvest spray of carbendazim reduced the storage loss on onion by 40%, while other fungicides like thiophanate methyl + thiram, thiabendazole, captan + benomyl, chlorothalonil and thiophanate methyl applied at different growth stages could not reduce storage losses. Mirage and Folicur bulb dressing resulted in the lowest bulb rot in shallots stored on wire mesh shelves. However, there was no significant difference in 2007 between any of the fungicide treatments and the non-treated control in bulb rot on wire mesh shelves. In the storage the most promising fungicide treatments were not highly satisfactory, this may suggest that there were other contributory factors to this problem. After harvest the bulbs could be mechanical wounded and soil may contain *Foc* spores adhering to healthy bulbs, when favorable temperature and humidity occurred in the storage the losses of bulbs due to FBR was increased (Rabinowitch and James, 1990). It has been reported that basal rot symptoms were manifested during storage of bulbs, which appeared healthy when they were harvested, and most of the damage from FBR was observed during storage (Stadnik and Dhingra, 1996). The 2006 storage bulb rot was more severe than that in 2007. It might be due to the higher incidence and severity in the field in first year than the second year.

This study indicates that a bulb dipping with Seed plus or a bulb dressing with Mirage has an excellent potential for control of FBR disease of shallot and without phytotoxicity problem. Therefore, we concluded that Seed plus and Mirage were the most effective bulb treatment fungicides for the management of FBR disease to achieve a good yield by reducing the disease incidence, severity in the field and bulb rot in storage. The possibility of controlling FBR disease of shallot with only one seed bulb treatment when applied at planting time by these fungicides looks promising and economical. This study shows that strategic use of fungicide seed treatments may have a place in an integrated management of shallot FBR in moderate and high-risk environmental conditions.

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